

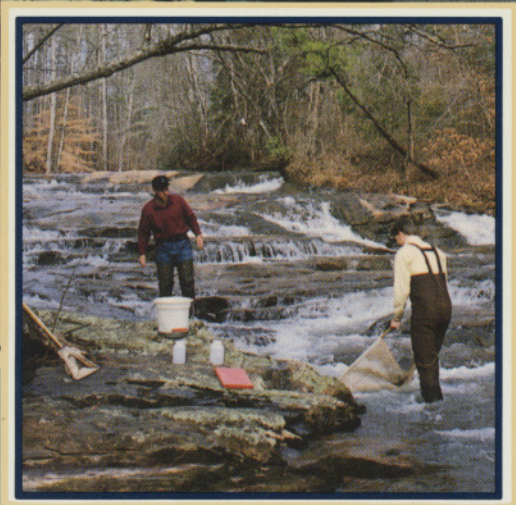
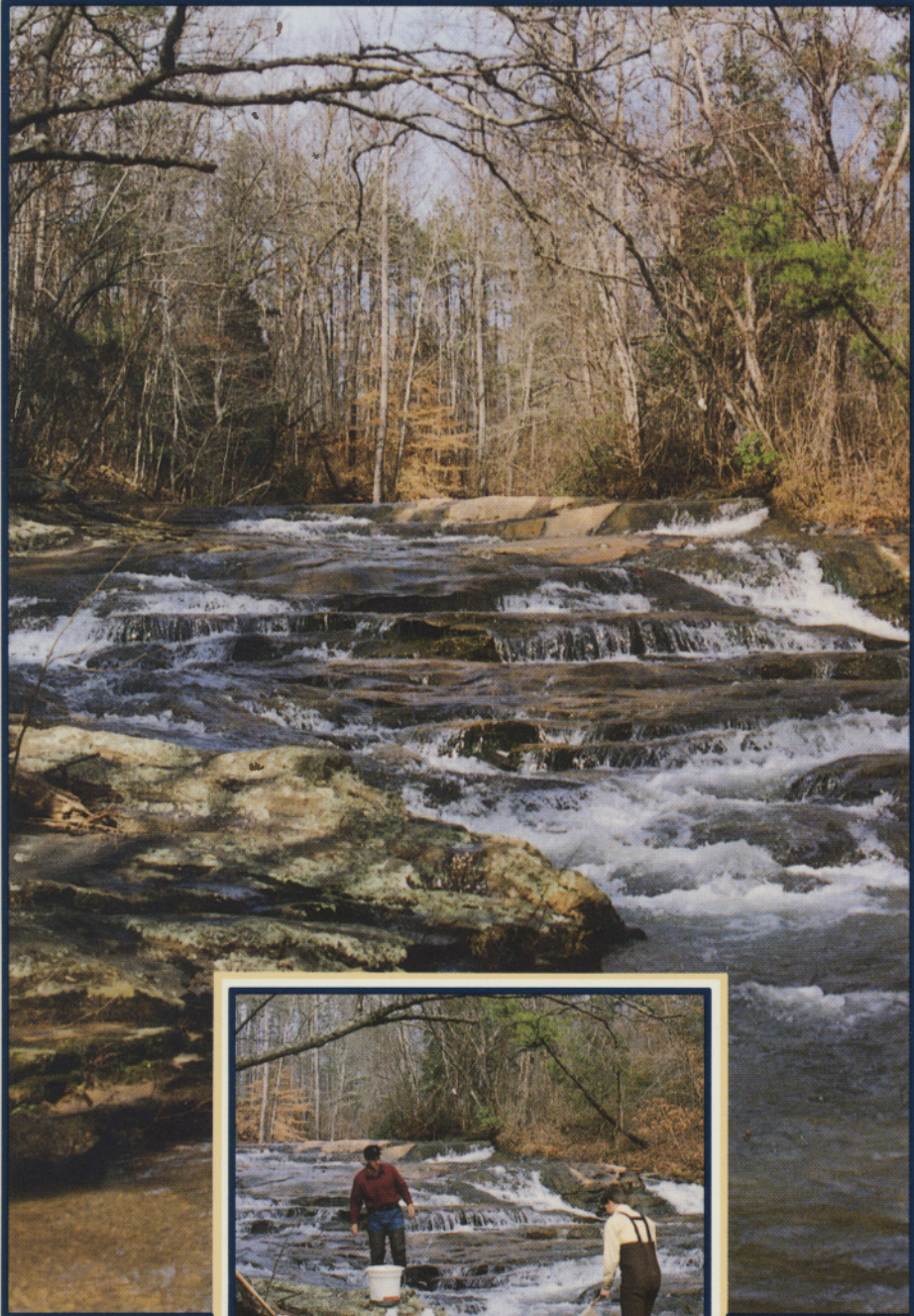
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Implementation
& Effectiveness Monitoring
of
Forestry

BEST MANAGEMENT PRACTICES

on Harvested Sites
in
South
Carolina

1993



▶ Section 1 —
Compliance with BMPs

Now ▶ Section 2 —
*Effectiveness Monitoring
of BMPs*

Implementation and Effectiveness Monitoring
of
**FORESTRY
BEST MANAGEMENT PRACTICES**

on Harvested Sites in South Carolina

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Best Management Practices

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COMPLIANCE

with

Forestry Best Management Practices

on Harvested Sites in South Carolina

INTRODUCTION

In South Carolina, silvicultural guidelines were first published in 1976 by the South Carolina Forestry Association. Best Management Practices for South Carolina's Forest Wetlands was published by the South Carolina Forestry Commission (SCFC) in 1989. The first attempt at monitoring Best Management Practices (BMP) compliance in South Carolina was completed in 1990. At that time, overall BMP compliance for the state was 84%. The current study was designed to build upon this initial monitoring effort by Hook et al. * to determine the level of compliance with BMPs as well as the major factors which affect BMP compliance for timber harvesting operations in South Carolina.

STUDY METHODS

'Site Location'

One hundred seventy-seven harvested sites were located in South Carolina for evaluation of BMP compliance. The number of sites selected was based on the

sample size needed for statistical analysis. BMP compliance checks were made on harvested sites that were no older than one year old. Most of the sites were logged between mid-1990 and mid-1991, and they were inspected during the spring and summer of 1991. Also, harvested sites had to be a minimum of 10 acres. No site was sampled that had been site prepared. Harvested sites were not required to be associated with streams or wetland areas as was the case in previous monitoring.

Selected sites were distributed throughout South Carolina in proportion to the volume of timber harvested. The average volume of timber harvested in individual counties was calculated over a three-year-period from 1986 through 1988 to eliminate annual variability. Harvest volumes came from unpublished annual timber harvest data collected by the U.S. Forest Service. The number of sites sampled within any particular county was in proportion to the per cent of that county's harvest in relation to the entire state. The number of sites located within individual counties ranged from one to eight sites. Sites were

*Hook, D.D., V. McKee, T. Williams, B. Baker, L. Lundquist, R. Martin, and J. Mills. 1991. A survey of voluntary compliance of forestry best management practices. South Carolina Forestry Commission. Columbia, South Carolina. 23p.

identified by SCFC foresters from fixed-wing aircraft and recent satellite imagery or aerial photography.

'Landowner Questionnaire'

SCFC foresters contacted all landowners whose sites were selected for BMP compliance checks.

Four categories of landowners were recognized for the purpose of this study: (1) non-industrial private landowners who own less than 1,000 acres of forest land, (2) non-industrial private landowners who own more than 1,000 acres of forest land, (3) public lands (both state and federal), and (4) industrial lands.

Prior to site inspection, landowners were questioned concerning their familiarity with BMPs, their use of a professional forester, their use of a written sales contract, and whether compliance with BMPs had been required of the harvesting contractor.

'BMP Compliance Inspection'

Site inspections were made during the spring and summer of 1991. The evaluations were per-



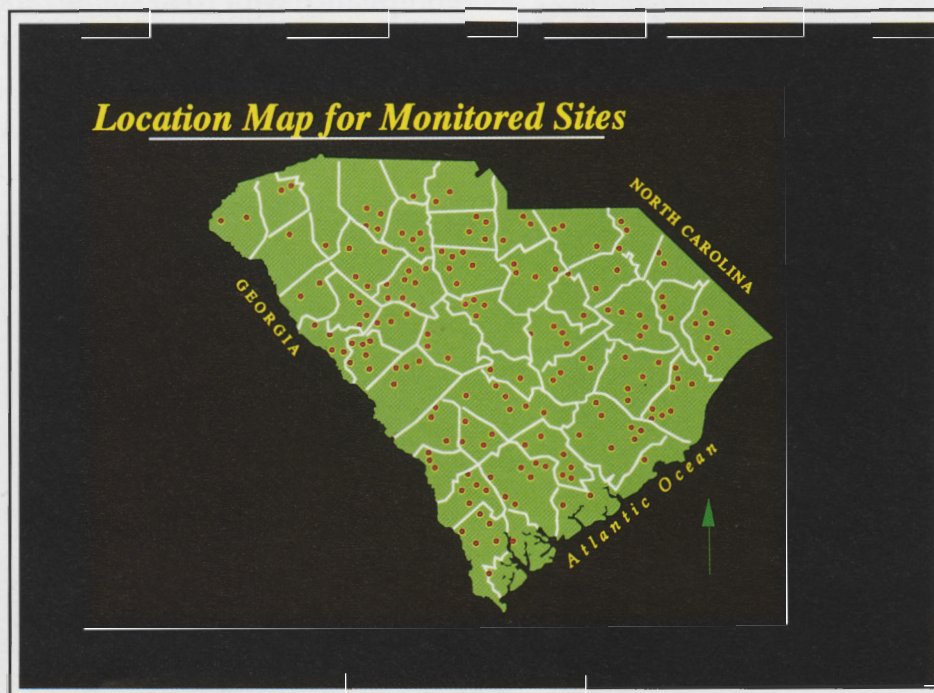
formed by a three-person team of SCFC foresters consisting of the forest hydrologist, assistant district forester, and the local project forester. The inspection covered compliance with BMPs in each of five categories: (1) road systems, (2) road stream crossings, (3) streamside management zones, (4) harvesting operations, and (5) log decks. Each major category was evaluated on a pass/fail basis depending on the responses to a series of yes/no questions within each category. Also, the overall compliance rating for each harvest operation was categorized as either excellent, adequate, or inadequate depending on the level of environmental disturbance. The overall compliance rating, though subjective, was based on compliance with specific BMPs as noted throughout the evaluation. When

sites were rated as inadequate, the major problems on that site were identified.

'Statistical Analysis'

Compliance values were computed for each of the five main BMP categories as well as for overall BMP compliance. A 95% confidence interval was calculated for each compliance value. Problems which contributed to non-compliance were identified for each of the major BMP categories and overall BMP compliance.

Nineteen variables, including site characteristics and management decisions, were identified which could have possibly affected the level of BMP compliance. All of these variables were evaluated through landowner interviews or by on-site inspection of the harvesting operations. Statistical analysis was performed on each of these variables, individually and in combination, to determine the significance of their relationship with BMP compliance.



177 harvested sites were evaluated for BMP compliance.

MONITORING RESULTS

BMP compliance checks were completed on 177 harvested sites between April 9, 1991 and July 24, 1991. Compliance with each of the five major BMP categories and overall BMP compliance is summarized below.

'Road Systems'

92%
acceptable

Compliance with road construction and maintenance BMPs was high when considering road stream crossings separately. Statewide, 137 out of the 177 sites that were evaluated involved roadwork.

Of these 137 sites, 126 (92%) sites had adequate BMP compliance and only 11 (8%) sites rated inadequate.

Inadequate ratings were due to the lack of adequate water diversion structures, inappropriate road slope, and emptying of road ditches into streams. In fact, all 11 sites with inadequate ratings had road ditches which emptied directly into streams. Both adequate and inadequate sites had low compliance with road stabilization BMPs. Road layout and filter strip width contributed to the low ratings for inadequate sites but were not the major problems.



The use of water diversion structures and seeding with grass created stable conditions on this road.



Severe erosion on this forest road could have been prevented with water diversion structures.

'Road Stream Crossings'

Compliance with road stream crossing BMPs was the lowest of all the major BMP categories. However, of the 177 sites inspected, only 12 sites involved road stream crossings. Of these 12 sites, five were constructed and maintained according to BMPs for a 41.7% compliance rating. Only roads that crossed perennial streams were evaluated in this study.

Sites with adequate ratings were all either bridged or culverted crossings, whereas sites with inadequate ratings were predominately culverted crossings with some ford and debris fill crossings. Most crossings that were inspected could not have been avoided. Where crossings received inadequate ratings, culverted crossings were generally undersized or improperly installed, and fill material was not stabilized. The impact of poorly designed crossings was generally visible downstream.

41.7%
acceptable



This culverted crossing was designed to carry 25-year-storm flows.



Installation of a properly sized culvert would have prevented this crossing from washing out.



SMZs were often extended to the top of the natural bluff, exceeding minimum width recommendations.



Disregard for stream protection on this site resulted in off-site water quality impacts.

'Streamside Management Zones'

Compliance with streamside management zone (SMZ) BMPs was the second lowest of all major BMP categories.

Of the 177 sites inspected, 58 sites had perennial streams which required SMZs. Forty-two of the sites were rated adequate (72.4%) and 16 sites were rated inadequate (27.6%). SMZs were not evaluated for intermittent or ephemeral streams in this study.

72.4%
acceptable

Sites with adequate SMZ ratings occurred only on low and moderate slopes. All sites with steep slopes (>20%) received adequate SMZ ratings. Inadequate SMZs were generally due to the total absence of SMZs rather than SMZs being narrower than recommended. In evaluating SMZs, the team did not find an SMZ inadequate if it was only slightly narrower than the recommended width. However, the loss of riparian canopy cover, the movement of vehicles in the SMZ, and the movement of sediment across the SMZ all contributed to inadequate ratings.

'Harvesting Operations'

The harvesting operation was evaluated on all 177 sites with 159 receiving adequate ratings (89.8%). Practices evaluated included: (1) the layout of the skid trails, (2) drainage crossings, (3) soil moisture conditions during logging, (4) degree of rutting, and (5) overall site impact. Sites impacted by skidding equipment were also evaluated by estimating the per cent of exposed mineral soil. Ruts were considered to be excessive if they were greater than 10 inches deep.

Skidding impact on sites with adequate harvest ratings was evenly split between low (<10%) and moderate (10-20%) levels of area impacted. In contrast, high site impact (>20%) predominated

on sites with inadequate ratings. This appeared to be caused by a combination of logging during wet soil conditions (as evidenced by deep rutting), using inappropriate equipment for site conditions, and poor skid trail design. The degree of deep rutting was unacceptable on 88.9% of the sites with inadequate harvesting compliance.

Skid trail crossings on all types of drainage features were evaluated including perennial, intermittent, and ephemeral streams as well as ditches or canals. The likelihood of finding a skid trail crossing for each drainage feature was greater for inadequate sites. The most common type of skid trail crossing on all sites was fords. Also, the use of

89.8%
acceptable



This skid trail had been water-barred and recently seeded with grass.



Poor skid trail location and a lack of water bars resulted in eroded sediment reaching the stream.

soil fill was noticeably higher on inadequate sites.

'Log Decks'

Compliance with log deck BMPs was high with 97.7% of all sites rated adequate. Only four sites, out of 177 sites inspected, were rated inadequate. Failed log decks were due to location either within primary streamside management zones and/or within an unstable wetland area when an upland site was available.

97.7%
acceptable

Overall BMP Compliance

Overall BMP compliance for South Carolina's monitoring program was 84.7%. Of 177 sites inspected, 54 sites rated excellent, 96 sites rated adequate, and 27 sites rated inadequate. Sites with inadequate compliance were evenly distributed across the state with the exception of a 10-county area centered around Florence where compliance was higher than average. The major problems that were identified were logging

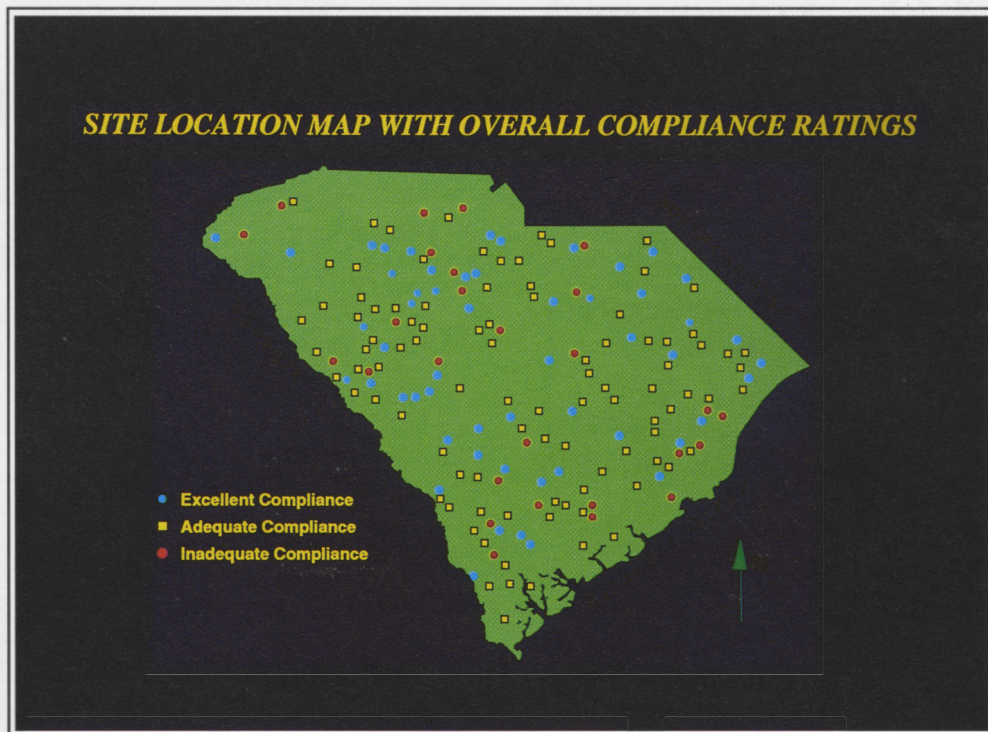
84.7%
acceptable



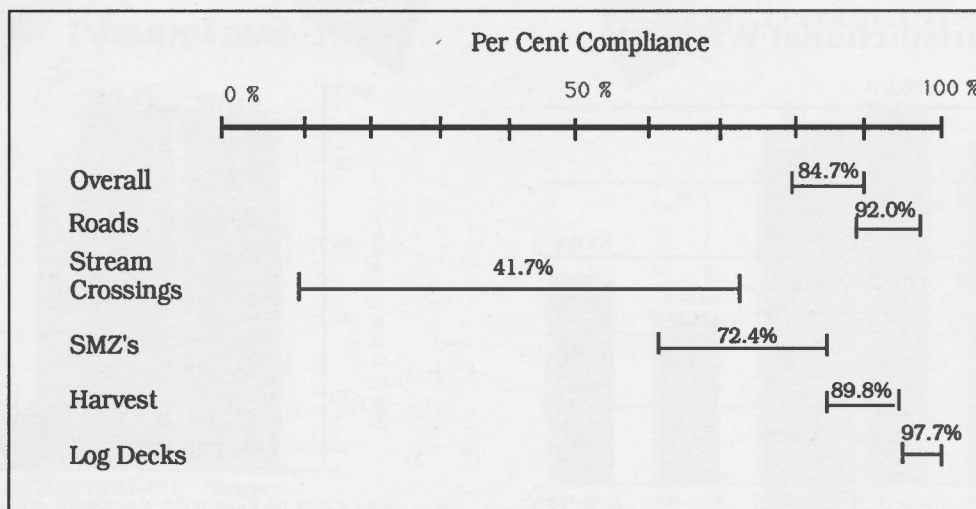
Oil spills and garbage at the log decks were rated as minimal on 86.7% of adequate sites and 50% of inadequate sites.

under wet soil conditions and inadequate SMZs.

Sites with excellent overall BMP compliance scored well on all individual BMP categories. Adequate sites scored well on all BMP categories except stream crossing BMPs which had 40% compliance. In contrast, inadequate sites scored low on all categories except for log deck BMPs. Road stream crossings appeared to be the most difficult BMP category with which to comply.



Of 177 sites inspected, 54 sites rated excellent, 96 sites rated adequate, and 27 sites rated inadequate.



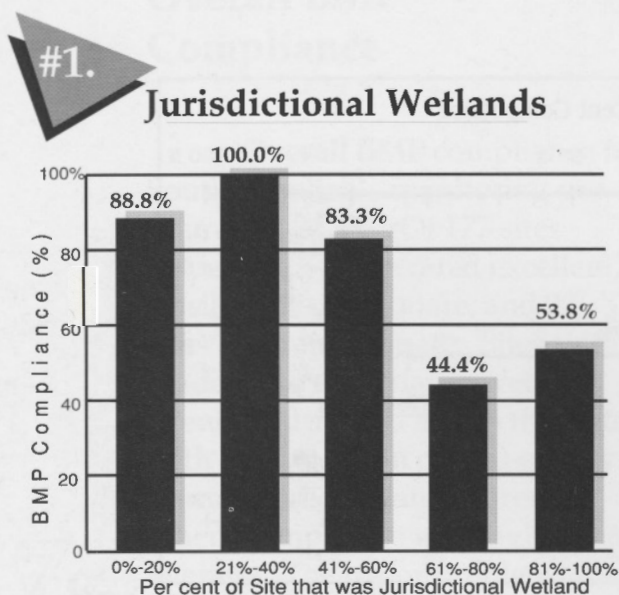
Compliance is shown for the 5 major BMP categories and overall BMP compliance along with 95% confidence intervals.

What *Variables* Affect BMP Compliance ?

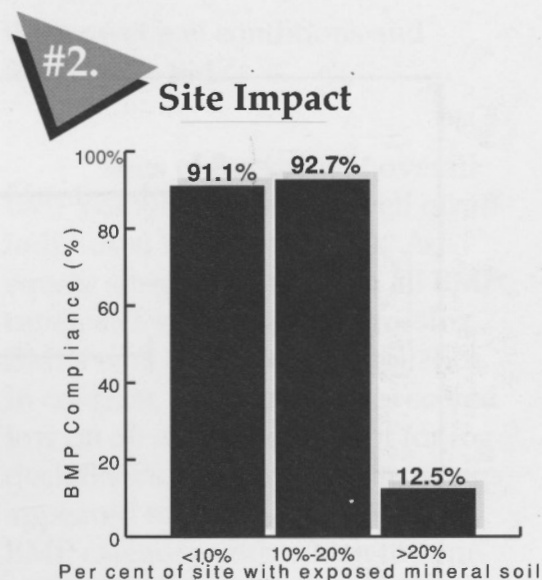
Nineteen variables were analyzed to determine their effect on BMP compliance.

- Presence of jurisdictional wetlands
- Per cent of site impacted
- Erosion hazard rating
- Logged under wet soil conditions
- Presence of perennial streams
- Terrain type
- Use of a professional forester
- Required compliance with BMPs
- Surface soil texture
- Landowner category
- Road construction/maintenance necessary
- Presence of Hurricane Hugo impact
- Soil drainage class
- Familiarity of landowner/manager with BMPs
- Land slope
- Harvest size
- Physiographic region
- Upslope land use
- Use of a sales contract

Six of the 19 variables were found to be significantly related to BMP compliance. Three of these variables are site characteristics and three are management decisions. Several of these variables are interrelated.



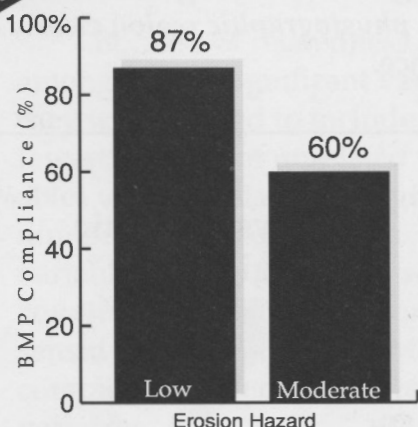
In general, BMP compliance fell for sites which were more than 60% jurisdictional wetland.



Sites with a high per cent of the site impacted by skidding equipment also had significantly lower compliance with BMPs.

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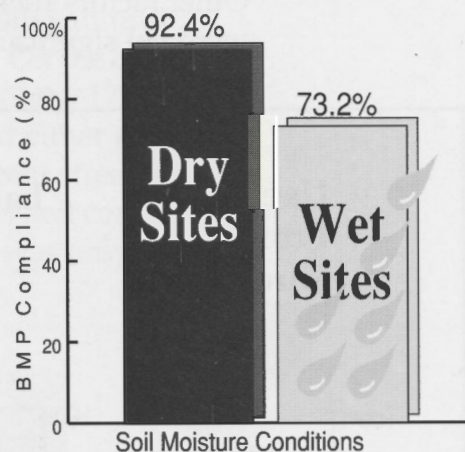
Erosion Hazard Ratings



Overall BMP compliance was significantly higher for sites with low erosion hazard than for those sites with moderate erosion hazard. No site received a high erosion hazard rating. Ratings depended on the soil type, slope, and the logging equipment used.

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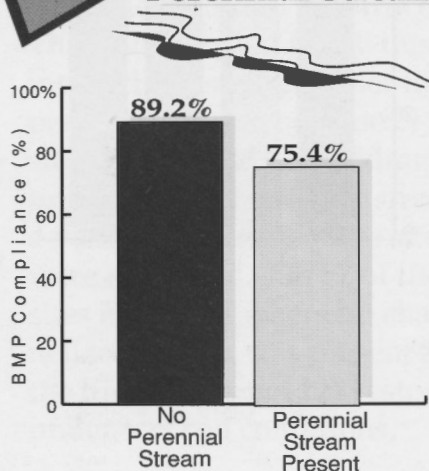
Logged During Dry/Wet Conditions



Compliance was 92.4% for sites logged during dry soil conditions and 73.2% for sites logged under wet soil conditions.

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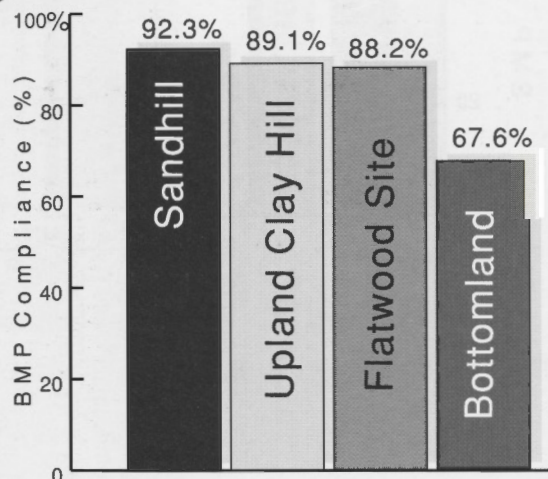
Perennial Streams



BMP compliance dropped significantly for sites which were closely associated with perennial streams.

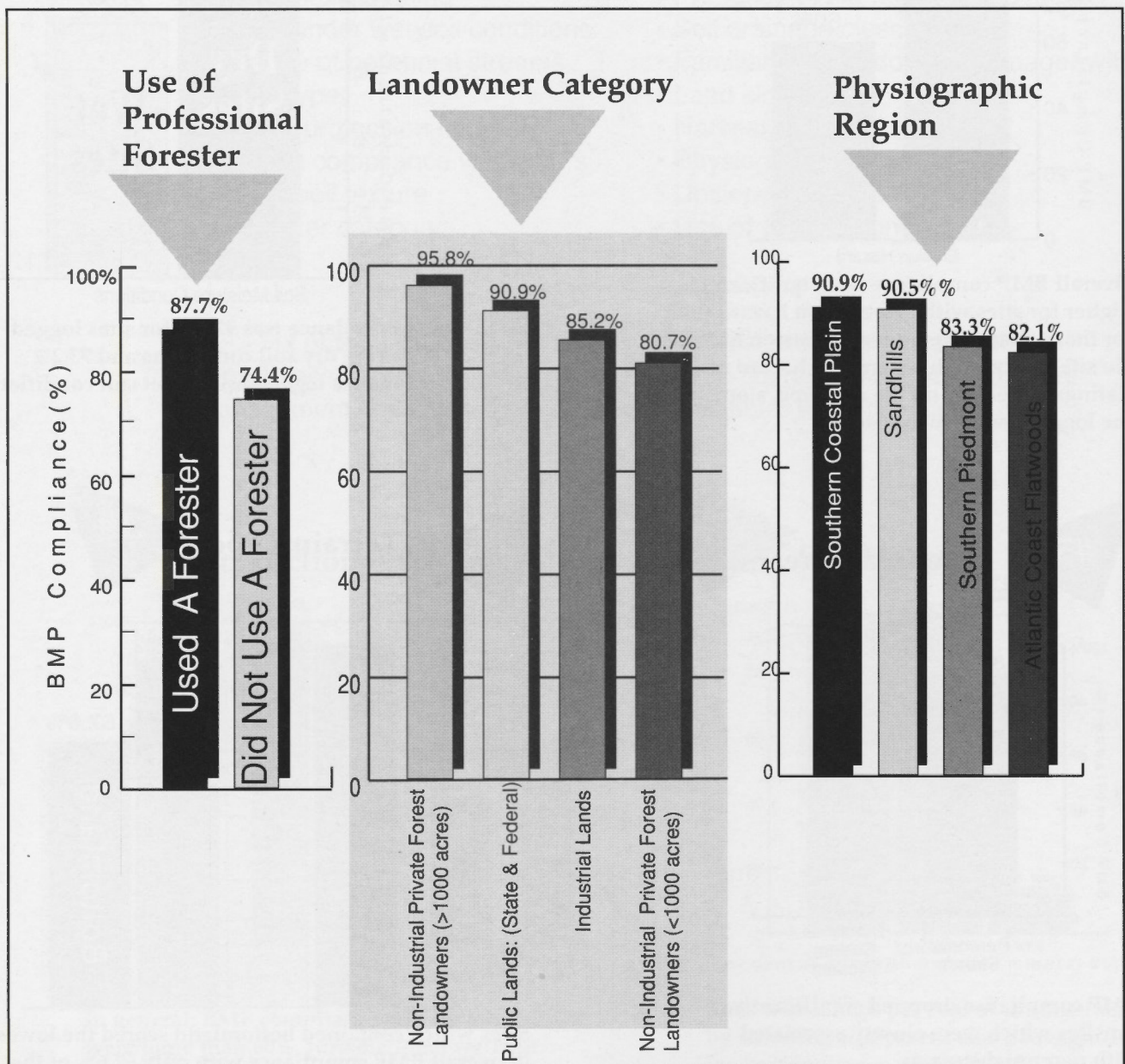
#6.

Terrain Types



Sites which contained bottomland scored the lowest in overall BMP compliance with only 67.6% of the sites being acceptable.

Of the remainder of the 19 variables which were analyzed, only the *use of a professional forester* was close to being statistically significant. Other factors such as *landowner category* and *physiographic region* clearly were not significantly related to BMP compliance.



Because of relatedness among the six significant variables, they were refined to include the fewest number of unrelated variables which explained the greatest number of inadequate sites. The variable *logging under wet soil conditions* proved to be more sensitive in determining BMP compliance than other related variables.

Two variables, presence of perennial streams and logged under wet soil conditions explained 26 of the 27 inadequate sites. The single unexplained inadequate site had a first-order stream which was impacted by road and skid trail construction. The team decided to call this an intermittent stream rather than a perennial stream because of its small watershed. By adding *presence of intermittent streams* as a variable, all inadequate sites were explained. On 52 of the 177 sites inspected where no channelized stream was present and the timber was not harvested under wet soil conditions,

compliance with silvicultural BMPs was 100%. On the other hand, on 125 out of the 177 sites inspected that had either perennial streams, intermittent streams, or logging under wet soil conditions, BMP compliance was only 78.4%.



CONCLUSIONS

During 1990 and 1991, silvicultural BMPs were implemented on 84.7% of the harvesting operations in South Carolina. Of the five major BMP categories, compliance was highest for log deck and road BMPs, 97.7% and 92.0%, respectively. Compliance was lowest for road stream crossings and SMZs, 41.7% and 72.4%, respectively. Compliance with harvesting BMPs was 89.8% with the major problems consisting of logging under wet soil conditions and skid trail crossings using soil as fill material.

The lack of compliance with silvicultural BMPs was caused by a failure of all landowners to identify and adequately protect sensitive sites. Sites which were the most critical to BMP compliance were sites with perennial and intermittent streams present. The most critical management decision which affected BMP compliance was the timing of logging during periods of wet soil conditions.

The voluntary non-point source pollution silvicultural program in South Carolina has been moderately successful in encouraging environmental protection. Existing regulatory programs, through both federal and state water quality legislation, will further increase pressure on landowners and professional foresters to improve environmental protection during harvesting operations.

RECOMMENDATIONS

Based upon the results of this study, compliance with silvicultural BMPs can be improved by redirecting the NPSP program to emphasize the following actions.

- 1 • *Silvicultural BMP manuals should be revised to clearly identify specific practices in order to reduce the subjectivity in BMP interpretation.*
- 2 • *BMP education and training programs should include all landowners rather than concentrating on non-industrial private forest landowners. Study results clearly indicated that differences in BMP compliance among landowner categories were insignificant.*
- 3 • *BMP education and training programs should emphasize the identification and protection of sensitive sites. In particular, sites with perennial streams, intermittent streams, or jurisdictional wetlands should be identified in the harvest planning process and these sites should be protected with applicable BMPs. Inclusion of wet weather logging restrictions in a timber sale contract is important in avoiding both on-site and off-site impacts.*
- 4 • *State forestry agencies should offer pre-harvesting site inspections as a service to all landowners in an effort to prevent environmental impacts. Critical BMPs involving road design, stream protection, and log deck location could be included in a complimentary inspection.*

EFFECTIVENESS MONITORING

of

Forestry Best Management Practices

on Harvested Sites in South Carolina

INTRODUCTION

State silvicultural non-point source pollution (NPSP) programs have relied upon the use of Best Management Practices (BMPs). However, the credibility of NPSP programs depends on the effectiveness of forestry BMPs in protecting water quality. State forestry agencies have depended upon indirect methods for demonstrating BMP effectiveness such as qualitative surveys. Such surveys evaluate the use of BMPs and predict sediment production, but do not measure aquatic parameters directly. Therefore, the need exists for a proven monitoring system which can accurately determine BMP effectiveness over a wide range of site conditions. The goal of this study was to evaluate the use of biomonitoring as a measure of BMP effectiveness on harvested sites in South Carolina.

Three BMP effectiveness techniques were evaluated: a BMP compliance inspection, a stream habitat assessment, and a benthic macroinvertebrate bioassessment.

STUDY METHODS

'Site Location'

A BMP compliance inspection was completed on 177 harvested sites that were chosen at random across South Carolina in 1991. These sites were screened to identify sites with perennial streams. Fifty-seven sites were associated with perennial streams. These 57 sites were further screened to determine their suitability for stream habitat assessment and benthic macroinvertebrate biomonitoring. Many streams were eliminated from consideration because of excessive impacts from other land uses. Subsequently, 27 (15%) of the 177 sites were found to be suitable for research purposes. The 27 sites were selected to represent the full range of logging impacts including jobs with excellent to inadequate BMP compliance. Both black and red river streams were evaluated that ranged from first to fourth order.

'BMP Compliance Inspection'



Site inspections were made during the spring and summer of 1991 by a three-person team of South Carolina Forestry Commission (SCFC) foresters. A four page evaluation form was completed for each site. Along with site characteristic information, the inspection evaluated compliance with BMPs in each of five categories: (1) road systems, (2) road stream crossings, (3) streamside management zones, (4) harvesting operations, and (5) log decks. Each major category

was evaluated on a pass/fail basis. Also, the entire harvesting operation was categorized as either excellent, adequate, or inadequate based on the level of environmental disturbance. When sites were rated as inadequate, the major problems on that site were listed. Statewide BMP compliance cannot be extrapolated from the compliance on these 27 sites since these sites were chosen in a non-random manner in order to sample the full range of logging impacts.

'Stream Habitat Assessment'



Stream width and depth were measured at each site.

Stream habitat evaluations were completed over a five-week period in the fall of 1991. A stream habitat assessment form was completed for each site both above and below the logging job where possible. When a reference site was not available above the logging operation, a nearby reference site was located on a neighboring stream of comparable size.

The stream habitat assessment generally followed EPA's Rapid Bioassessment Protocols (RBPs).^{*} Seven parameters were evaluated that affected the quality and quantity of benthic

macroinvertebrate habitat: (1) available macroinvertebrate habitat, (2) cobble embeddedness, (3) logging slash within the stream, (4) pool/riffle or run/bend ratio, (5) canopy cover, (6) dominant streamside cover, and (7) bank vegetative stability. Parameters were evaluated and scored for the downstream and reference stations, with higher scores reflecting better biological habitat. The impact of logging on stream habitat was determined by dividing the total habitat assessment score of the downstream station by the reference station's total score. The stream habitat below the logging operation was expressed as a percent of the reference condition. RBPs allowed for discernment of four levels of habitat degradation. Parameters were ranked based on their cumulative change in score from reference to downstream conditions for all 27 sites.

The stream habitat assessment was compared to the BMP compliance inspection for agreement. BMP compliance values were calculated for each level of stream habitat impact. Also, chi-square analysis was used to test for significant differences between

^{*}Plafkin, E.T., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. U.S. EPA, Office of Water, EPA/444/4-89-001/ Washington, D.C.

these two types of impact assessment. In addition, the BMP compliance ratings were used to redefine EPA's criteria for stream habitat assessment. The RBP's four levels of impact were consolidated into two categories, impacted and unimpacted to increase the accuracy of statistical tests. BMP compliance values were calculated for these new impact criteria, and chi-square analyses were completed to test for significant differences between stream habitat assessments and BMP compliance check assessments.

'Benthic Macroinvertebrate Biomonitoring'

Field collection procedures, laboratory insect identification, and data interpretations were patterned after RBP III. Benthic macroinvertebrate samples were collected both above and below each of the 27 harvesting operations when possible. The preferred reference site was located upstream from the logging operation. If the area above the site had been impacted by other activities, then a nearby unimpacted stream was selected as a reference. This was necessary on only seven (26%) of

the 27 sites. Multiple nearby reference streams were used when possible. Macroinvertebrate habitats were sampled in proportion to their abundance. Reference stream segments as near in character as possible to the downstream sample area were chosen.

Benthic macroinvertebrate sampling was completed in the fall of 1991. Sampling was confined to one man-hour time periods to



Macroinvertebrate habitats were sampled in proportion to their abundance.

allow for comparisons between sites. Insects were picked in proportion to their abundance and

combined into a composite sample for laboratory identification. Insect identification was "blind" since the entomologist was not aware of the sampled site's location. All insects were identified to the lowest taxonomic level possible.

Benthic macroinvertebrate bioassessments were based on the metrics listed for RBP III. Each metric was designed to analyze a unique component of the insect community. All RBP III metrics were used with the following exceptions: the Hilsenhoff Biotic Index was replaced with an unpublished regional biotic index developed by the North Carolina Department of Environmental Management, and the ratio of EPT and Chironomid abundances was not calculated since chironomids were not collected. The RBP III metrics used were (1) taxa richness, (2) biotic index, (3) ratio of scrapers to filtering collectors, (4) the per cent contribution of the dominant taxon, (5) the EPT index, (6) the community loss index, and (7) the ratio of shredders to other functional feeding groups. A biological condition score, ranging from zero to six points, was as-

signed based on the value of each metric. Scores were totaled and divided by the maximum possible score, usually 42 points, to determine the overall bioassessment for the site. RBP III allows for four levels of impact assessment. The metrics were ranked based on the cumulative changes in scores from reference to downstream conditions for all 27 sites.

The benthic macroinvertebrate assessment was compared to the BMP compliance check for agreement. BMP compliance was calculated for each level of benthic macroinvertebrate assessment impact. Also, chi-square analysis was used to test for significant differences between these two types of impact assessments. In addition, the BMP compliance ratings were used to redefine EPA's criteria for assessing benthic macroinvertebrate impact. RBP III's four levels of impact were consolidated into two categories, impacted and unimpacted, primarily for the purpose of increasing the accuracy of statistical tests. BMP compliance was calculated for these new impact criteria, and chi-square

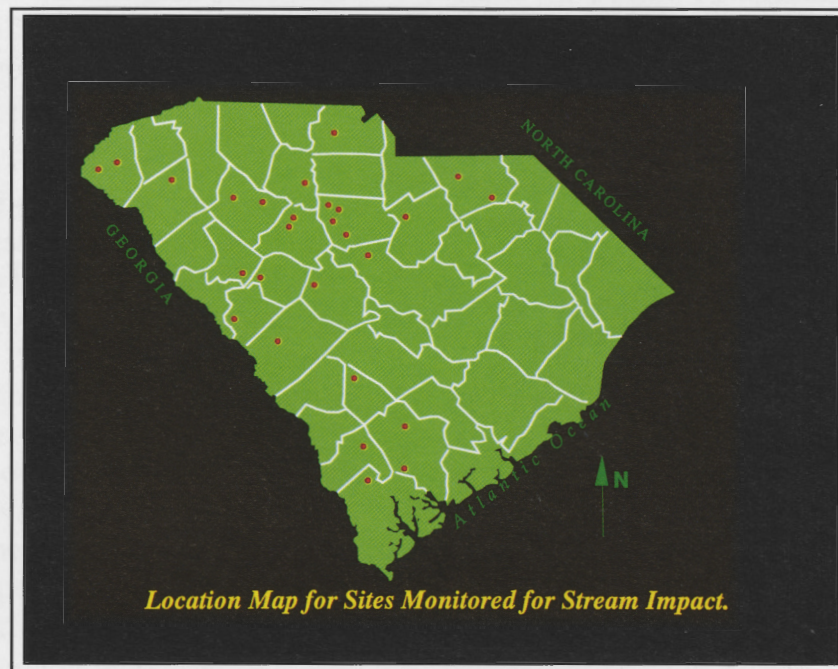
analysis was completed to test for significant differences in benthic macroinvertebrate assessments and BMP compliance inspection assessments.

'Weight-of-the-Evidence Approach'

The effectiveness of BMPs in protecting water quality of streams associated with logging operations was evaluated with a weight-of-the-evidence approach. The BMP compliance check served as an indirect measure of effectiveness, while the stream habitat assessment and the benthic macroinvertebrate bioassessment served as direct measures of effectiveness. An overall "verdict" was determined for each site based on the weight of all available evidence. The verdict and each effectiveness technique were evaluated on a pass or fail basis. Sites were revisited and re-evaluated when difficulty existed in arriving at an overall verdict. The accuracy of each technique was calculated by dividing the number of agreements with the verdict by the total number of sampled sites.

STUDY RESULTS

'Site Description'



Twenty-seven harvested sites with perennial streams were sampled during October and November of 1991. They were located in all five physiographic regions of South Carolina: Blue Ridge Mountains (1), Southern Piedmont (17), Carolina Sandhills (4), Southern Coastal Plain (1), and Atlantic Coast Flatwoods (4). Sites were distributed evenly across the state except for the northern reaches of the Southern Coastal Plain and the Atlantic Coast

Flatwoods where there was a lack of sites with associated streams.

Nineteen red river streams, originating in the Blue Ridge Mountains or Southern Piedmont, were monitored. These streams ranged in size from a small stream, two feet in width with two-inch-deep runs, to the 25-foot-wide Shaw's Creek in Aiken County with three-foot-deep runs and four-foot-deep pools. Eight black

river streams, originating in the Coastal Plain, were monitored. These streams ranged in size from a small two-foot-wide first-order stream with three-inch-deep runs to the 25-foot-wide Little Salkahatchie River in Bamberg County with four-foot-deep runs. All streams were sampled during baseflow conditions.

'BMP Compliance Inspection'

Ratings for the 27 monitored logging operations ranged from excellent to inadequate for overall BMP compliance. BMP compliance was excellent on 11 sites and adequate on 6 sites for a total of 17 (63%) acceptable harvesting operations. Compliance was inadequate on 10 (37%) of the 27 sites. Statewide BMP compliance for the 177 harvested sites was 84.7%. Of the 177 sites that were inspected, 54 sites rated excellent, 96 sites rated adequate, and 27 sites rated inadequate. BMP compliance was lower for the 27 sites that were used for effectiveness monitoring because they were selected in a non-random manner specifically to sample the full range of logging impacts.

Evaluated impacts ranged from sites with no problems to sites with both off-site water quality and on-site timber productivity impacts. The range of impacts was noticeable in the evaluation of the individual BMP categories: (1) road systems, (2) road stream crossings, (3) streamside management zones, (4) harvest operations, and (5) log decks. The 11 sites with excellent overall BMP compliance received acceptable ratings on all individual BMP categories. The six sites which received adequate overall BMP compliance ratings were either rated acceptable on all individual BMP categories or on all but one category. In contrast, the majority of sites with inadequate overall BMP compliance failed two or more of the major BMP categories. Streamside management zone BMPs were the most frequently violated BMPs on these 27 sites. Other problems on the 10 inadequate sites included the following: (1) logging under excessively wet soil conditions, (2) improperly designed road and skid trail crossings, (3) lack of water diversion structures on roads, (4) excessive rutting, and (5) use of improper logging equipment for site conditions.

'Stream Habitat Assessment'

Using EPA's criteria, stream habitat ratings below the 27 monitored logging operations ranged from "non-supporting" for benthic macroinvertebrates to conditions "comparable to reference." Thirteen (48%) of the 27 sites were basically unimpacted, scoring from 89.4% to 130.2% of the reference sites' scores. Five (19%) of the 27 sites were rated as "supporting" conditions for benthic macroinvertebrates, scoring from 76.4% to 86.5% of reference sites' scores. An additional five sites were "partially supporting" scoring from 60.3% to 70.0% of reference site conditions. The final four sites were rated as "non-supporting" scoring from 51.7% to 59.1% of reference site conditions. Twenty (74%) of the 27 sites had upstream reference sites, while seven sites required regional references.

For those sites where BMP compliance was inadequate, stream habitat was impacted negatively by the introduction of excessive amounts of both large woody debris and sediment. Of the seven metrics used to determine impact level on stream habi-

tat, the introduction of large woody debris accounted for the greatest change in stream habitat from reference conditions. The increase in cobble embeddedness due to sediment and the loss of available macroinvertebrate habitat and riparian canopy cover each accounted for substantial changes from reference conditions. The remaining metrics, i.e., pool/riffle ratio, dominant streamside cover type, and bank stability accounted for only minor changes in stream habitat.

Downstream sites which scored well on the stream habitat assessment tended also to score well on the BMP compliance check. Downstream sites which were comparable to reference conditions had the highest per cent BMP compliance, 92.3%. Sites with severe stream habitat impacts, scored as "non-supporting," averaged only 25.0% in BMP compliance. Chi-square analysis supported the relationship between the BMP compliance check and the stream habitat assessment.

The four levels of impact recommended by EPA were redefined into two impact levels,

unimpacted versus impacted, to describe the observed field conditions more accurately. Impacted stream habitat was evident when the stream habitat assessment for the downstream site was less than 77% of the reference site's score. Conversely, stream habitat impacts were not considered significant if downstream stations were rated as greater than or equal to 77% of the reference conditions. *Using this criterion, BMP compliance was 88.2% for sites with unimpacted stream habitats and was 20.0% for sites with impacted stream habitats.* Considering two levels of stream habitat impacts and BMP compliance on a pass/fail basis, chi-square analysis indicated a highly significant relationship.

'Benthic Macroinvertebrate Bioassessment'

The benthic macroinvertebrate bioassessments for the 27 monitored sites ranged from non-impaired to moderately impaired conditions using EPA's criteria. Thirteen sites were classified as non-impaired with another 13 sites rated as only slightly impaired. Only one site was classified as moderately

impaired. Twenty of 27 sites had upstream reference sites available. Four sites were compared to single regional reference streams, and three sites were compared to multiple regional reference streams. Downstream sites ranged from 38.1% to 100.0% of reference conditions.



The macroinvertebrate sample sizes were sufficient to evaluate the stream impacts accurately. The number of organisms per sample for one man-hour of collection time averaged 156 for downstream sites and 165 for reference sites. Since first- to fourth-order perennial streams were sampled, the smallest first- and second-order forested streams were typically low in taxa richness

regardless of BMP compliance. The majority of the 57 samples were of sufficient size to meet EPA's sample size criteria. Only 13 samples (23%) contained less than the desired 100 organisms.

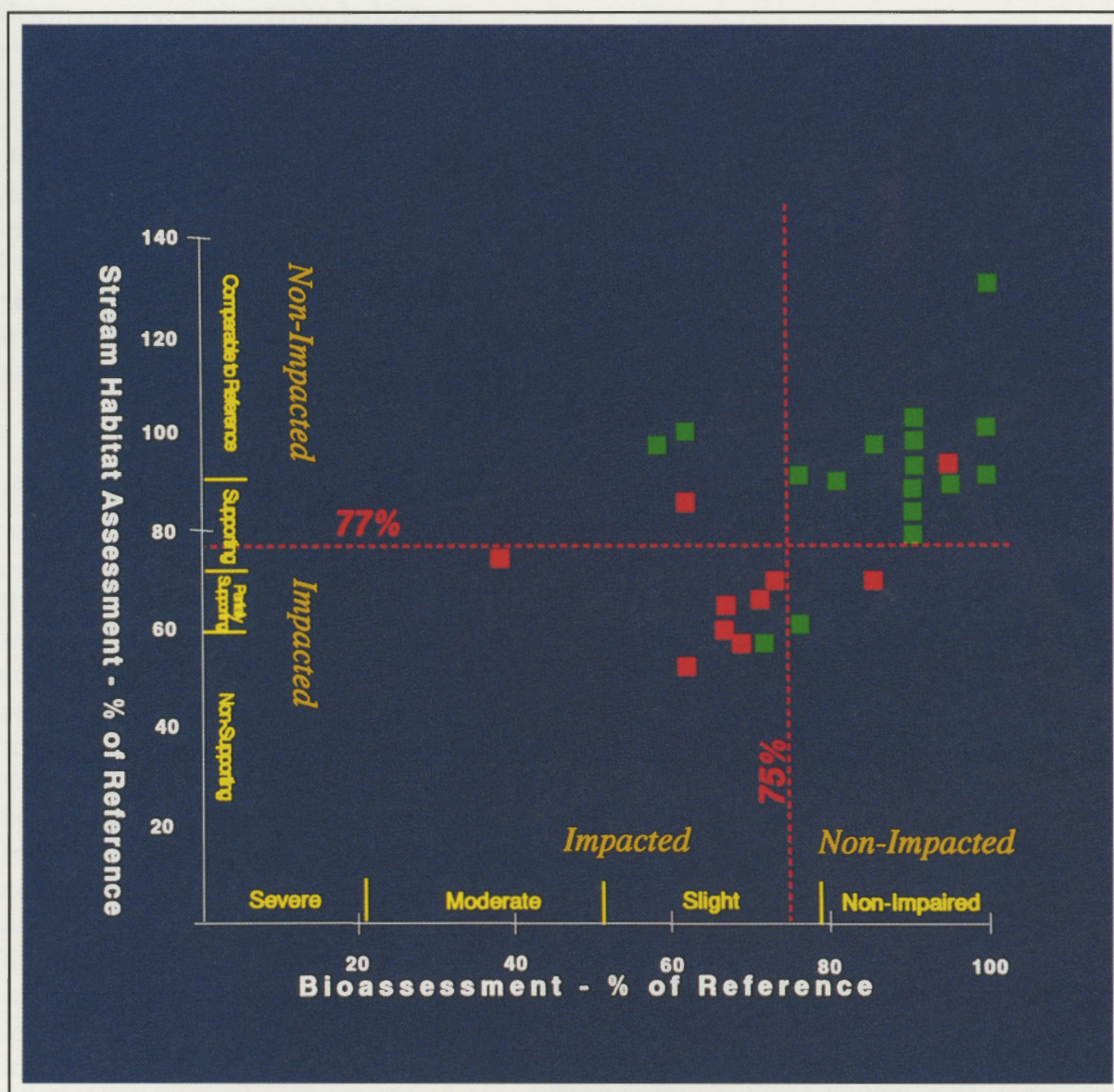
The seven metrics used in the bioassessment were, collectively, sensitive to varying levels of impact to macroinvertebrate community structure. On the majority of the sites that were rated as non-impaired, minor impacts were observed on only one metric or none at all. However, on the majority of sites rated with some level of impairment, a minimum of four metrics were observed to be impacted. The four metrics that were the most consistently associated with impacts observed in this study were: (1) the per cent contribution of the dominant taxon, (2) the ratio of shredders to the total sample size, (3) the EPT index, and (4) the ratio of scrapers to filtering collectors. Two of these four criteria (the ratio of shredders to the total sample size and the ratio of scrapers to filtering collectors) reflected changes in the insect functional feeding groups.

Sites which scored well on the benthic macroinvertebrate

bioassessment tended to score well on the BMP compliance check. Non-impaired sites averaged 84.6% BMP compliance versus 46.2% compliance for slightly impaired sites. The single site rated as having moderate impairment rated inadequate on the BMP compliance check. Statistical analysis confirmed the relationship between the bioassessment and the BMP compliance check.

The four levels of impact recommended by EPA were redefined into two impact levels, non-impaired versus impaired, to describe the observed field conditions more accurately. Only one site was rated as moderately impaired, and no site was severely impaired by the logging operation. Using 75% of reference conditions as the break-point between impaired and non-impaired ratings, 16 of the 27 sites were rated as non-impaired and 11 sites as impaired. BMP compliance was 87.5% and 27.3% for non-impaired and impaired sites, respectively. A highly significant relationship was statistically demonstrated between the benthic macroinvertebrate bioassessment and the BMP compliance check.

The three techniques for evaluating BMP effectiveness resulted in similar water quality assessments on the majority of the sites.



Each Point Represents the BMP Compliance Rating for a Site

Excellent/Adequate Sites = Green
Inadequate Sites = Red

'Weight-of-the-Evidence Approach'

The stream habitat assessment and the benthic macroinvertebrate bioassessment resulted in comparable impact assessments for the majority of the 27 streams that were evaluated. However, the stream habitat assessment tended to be more discriminatory with sites being rated over the entire range of impact assessments.

The stream habitat assessment and the benthic macroinvertebrate bioassessment also generally agreed with the indirect measure of effectiveness, the BMP compliance rating. Sites with BMP compliance ratings of excellent and adequate generally showed no impact on either the stream habitat or the benthic macroinvertebrate community structure. However, inadequate sites showed a slight level of impact on the benthic macroinvertebrate bioassessment and a moderate to severe impact on the stream habitat assessment. Although in general agreement on the level of BMP effectiveness, the three approaches differed in the assessment of four sites when comparing the BMP compliance

check to the stream habitat assessment and of five sites when comparing the BMP compliance check to the benthic macroinvertebrate bioassessment. Three sites that were rated inadequate by the BMP compliance check passed either the benthic macroinvertebrate bioassessment or the stream habitat assessment. One site that rated adequate by the BMP compliance check failed both of the direct measures of effectiveness. Also, one site which rated an excellent by the BMP compliance check was rated non-impacted by the bioassessment, but was rated impacted by the stream habitat assessment.

A weight-of-the-evidence approach was taken to determine the definitive "verdict" for site evaluation. The verdict as well as each of the three effectiveness measures was evaluated on a pass or fail basis. For 26 of the 27 sites, the verdict was in agreement with two or more of the three assessment measures. Only on one site did the verdict differ from a conclusion based solely on the majority ruling of the three effectiveness techniques. This site was found to be inadequate because of a poorly designed road stream crossing.

When the stream crossing failed during a storm event, the sediment evidently was dispersed far beyond the site boundary. In this case, the site's verdict agreed with the BMP compliance check rather than the stream habitat assessment and benthic macroinvertebrate bioassessment. Two sites were revisited to re-evaluate BMP effectiveness where difficulty existed in arriving at the overall verdict.

The accuracy of each of the three BMP effectiveness measures was determined by comparing each technique's assessment with the overall verdict. The indirect measure of effectiveness, the BMP compliance check, was the most reliable effectiveness measure, scoring 96.3% in accuracy. The stream habitat assessment and the benthic macroinvertebrate bioassessment achieved similar accuracy ratings, 88.9% and 85.2%, respectively. No individual effectiveness measure resulted in complete accuracy in evaluating the level of impact resulting from logging operations on the 27 sites. Highest accuracy was attained by using all three techniques and by re-evaluating sites where discrepancies existed.

Weight of the Evidence Approach				
Site #	BMP Compliance Check	Habitat Assess.	Bioassessment	Verdict
1-2	+	+	+	+
1-5	+	+	+	+
1-12	-	-	-	-
1-14	+	+	+	+
4-4	+	+	+	+
4-13	+	+	+	+
4-15	+	+	+	+
4-22	+	+	+	+
4-25	+	+	-	+
4-30	+	+	+	+
4-31	+	-	+	+
4-36	+	+	+	+
4-38	-	+	+	-
4-39	+	+	+	+
4-40	-	-	-	-
5-1	-	+	-	-
5-6	+	+	+	+
5-19	-	+	-	-
6-3	+	+	+	+
6-4	-	-	+	-
6-5	+	+	+	+
6-8	-	-	-	-
6-11	-	-	-	-
7-3	+	+	-	+
7-7	-	-	-	-
7-17	-	-	-	-
7-26	-	-	-	-

A verdict was reached based on the weight-of-the-evidence. Disagreements with the verdict (highlighted blocks) were used to calculate the accuracy of each method.



CONCLUSIONS

This study demonstrated that on sites with perennial streams, BMP effectiveness can be assessed with reasonable accuracy by using a weight-of-the-evidence approach consisting of a BMP compliance check, a stream habitat assessment, and a benthic macroinvertebrate bioassessment. For the 27 study sites, implementation of silvicultural BMPs during harvesting operations was sufficient for the protection of the water quality of associated streams based on two direct measures of water quality. A weight-of-the-evidence approach should be considered by state and federal forestry and water quality agencies as an effective technique for assessing BMP effectiveness. On sites without perennial streams or on sites with streams that are already impacted by other land uses, BMP compliance monitoring by qualified professionals should be accepted as a reliable technique since this indirect technique was just as accurate in evaluating BMP effectiveness as the two direct assessment techniques.

